

3.2 EXPOSURE ASSESSMENT

Evaluating exposure for the PWB CTSA involves a series of sequential steps. The first step is characterizing the exposure setting, which includes describing the physical setting and characterizing the population(s) of interest and their activities that may result in exposure. These are described in Section 3.2.1 for both workplace and surrounding population (ambient) exposure.

The next step is selecting a set of workplace and population exposure pathways for quantitative evaluation from the set of possible exposure pathways. This is discussed in Section 3.2.2.

Next, chemical concentrations are collected or estimated in all media where exposure could occur. For the MHC processes, this consists of collecting existing concentration data from workplace monitoring, estimating the chemical concentrations in the MHC baths, and performing fate and transport modeling to estimate workplace and ambient air concentrations (Section 3.2.3).

The exposure-point concentrations and other exposure parameters are combined in exposure models to estimate potential dose rates (PDRs) for all quantified pathways. These exposure models and parameter values are described in Section 3.2.4. The final step, characterizing uncertainties, is in Section 3.2.5.

Because this CTSA is a comparative evaluation, and standardization is necessary to compare results for the alternative processes, this assessment focuses on a “model” (generic) PWB facility and uses aggregated data. In addition, this assessment focuses on exposure from chronic, long-term, day-to-day releases from a PWB facility rather than short-term exposures to high levels of hazardous chemicals as there could be with a fire, spill, or periodic releases. Due to the limited resources available to the project and the lack of information to characterize such releases, high level, acute exposures could not be assessed.

3.2.1 Exposure Setting

Characterizing the exposure setting includes the following steps:

- Characterizing the physical environment (in this case, a model PWB facility, its MHC process area, and the surrounding environment).
- Identifying potentially exposed workers and their activities.
- Identifying any potentially exposed populations, human or ecological, that may be exposed through releases to the ambient environment from PWB facilities.
- Defining the exposure scenarios to evaluate. (As used here, the term *scenario* refers to a specified physical setting, exposed population, and activities that may result in exposure.)

Physical Environment

IPC Workplace Practices Questionnaire and Performance Demonstration data collected for 59 PWB facilities and their MHC process areas were used to characterize a model PWB facility. Information obtained from these sources includes the following:

- Regarding MHC process alternatives, the IPC Workplace Practices Questionnaire database includes information from 36 electroless copper facilities, two carbon facilities, one conductive polymer facility, four graphite facilities, one non-formaldehyde copper facility, two organic-palladium facilities, and 13 tin-palladium facilities.
- Of these facilities, 48 are independent and the other 11 are original equipment manufacturers (OEMs) who manufacture PWBs solely for use in that company's products.
- The size of the PWB manufacturing area ranges from 3,721 to 400,000 ft², with a geometric mean area of 33,800 ft².
- The size of the MHC process room ranges from 120 to 60,000 ft², with a geometric mean of 3,760 ft².
- The number of days per year the MHC line operates ranges from 80 to 360, with an average of 250 days/year and a 90th percentile of 306 days/year.
- The total PWB processed per year ranges from 24,000 ssf per year to 6.24 million ssf per year, with a geometric mean of 351,670 ssf per year.
- Temperature of the process room ranges from 60 to 94 °F, with an average of 75 °F.
- All 59 facilities responding to the question reported the use of some type of ventilation in the process area. A smaller number of facilities provided more specific information on the type of ventilation and air flow rates. Reported air flow rates range from 7 to 405,000 ft³/min. with a geometric mean of 6,100 ft³/min. Of the facilities reporting air flow rates, the types of ventilation reported are as follows:
 - Seven facilities reported using both local and general ventilation systems.
 - Six facilities reported using only general ventilation.
 - Twenty-three facilities reported using only local ventilation. (However, they may not have consistently reported general ventilation.)
 - One facility did not specify either local or general ventilation.

The initial intent was to focus on a generic small- to medium-sized facility that manufactures $\leq 6,000$ ssf of PWB per day. However, larger facilities are now included in the database to account for all of the performance demonstration sites and all categories of process alternatives. The conductive ink facility is not included in this assessment.

The data summarized here are used to broadly characterize the exposure setting (i.e., a model PWB facility and MHC process area). Data used in the exposure models are discussed further in Section 3.2.4. Based on the workplace practices data and using arithmetic averages or geometric means, a model facility has the following characteristics:

- Is independent (rather than OEM).
- Uses 33,800 ft² of facility space in the PWB operation.
- Contains the MHC process in a room 3,760 ft² in size.
- Operates an MHC line 250 days/year.
- Manufactures 350,000 ssf of PWB per year.
- Is 75 °F in the process room.
- Has a typical ventilation air flow rate in the process area of 6,100 ft³/min.

Potentially Exposed Populations

Potentially exposed populations include both workers in the PWB facilities and ecological and human populations in the vicinity of the facilities. Each of these populations is discussed briefly below.

General Employee Information from the IPC Workplace Practices Questionnaire.

A summary of IPC Workplace Practices Questionnaire data pertaining to employees at PWB facilities includes the following:

- The number of full-time employee equivalents (FTEs) ranges from 8 to 1,700, with a geometric mean of 103.
- The number of employee work days per year ranges from 200 to 360, with an average of 268 days/year. The number of days per year the MHC line operates is used to characterize worker exposure from MHC line operation, rather than the overall employee work days per year, because the latter could include workers not in the MHC process area or time when the MHC line is not in operation.
- The MHC process line operates from 1 to 12 hours/shift, with an average of 6.8 hours/shift.
- Fifty-eight out of 59 facilities reported a first shift, 52 a second shift, 29 a third shift, and one reported a fourth shift (one facility operates the second but not a first shift). For MHC operation, 54 facilities reported a first shift, 43 a second shift, 16 a third shift, and one reported a fourth shift. This exposure assessment uses first shift data as representative.
- Types of workers in the MHC process area include:
 - Line operators.
 - Laboratory technicians.
 - Maintenance workers.
 - Supervisory personnel.
 - Wastewater treatment operators.
 - Contract workers.
 - Other employees (i.e., manufacturing engineer, process control specialist).

General Population Outside the Facility. PWB facilities included in the IPC Workplace Practices Questionnaire and Performance Demonstration database are located in various cities in the U.S. and Europe. Many are in southern California. This assessment estimates potential exposure to a hypothetical community living near a model PWB facility.

Exposure to ecological populations could also occur outside a PWB facility. In past CTSAs, concentrations have been estimated for surface water to assess potential exposure to aquatic organisms. However, as discussed in the Source Release Assessment (Section 3.1), data limitations preclude estimating releases to surface water. Ecological toxicity and hazard for potential releases to surface water (based on bath constituents used in each alternative) are addressed in Section 3.3.

Workplace Exposure Scenarios

A scenario describes the exposure setting, potentially exposed populations or individuals, and activities that could lead to exposure. For workplace exposures, the setting involves the MHC process in a PWB facility. The Workplace Practices data are used here to determine the types of workers who may be exposed and to characterize those worker's activities. Worker activities include working in the process area, MHC line operation, chemical bath sampling, chemical bath additions, chemical bath replacement, rack cleaning, conveyor equipment cleaning, and filter replacement.

Working in the Process Area. Exposure via inhalation of airborne chemicals is possible to workers in the MHC process area. Because of this, the questionnaire included questions about the types of workers who might be present in the area. Out of 59 facilities responding to this question:

- Fifty-nine have line operators in the MHC process area during the first shift.
- Fifty-two have laboratory technicians in the MHC process area.
- Thirty-eight have maintenance workers in the MHC process area.
- Fifty have supervisory personnel in the MHC process area.
- Thirty-six have wastewater treatment operators in the MHC process area.
- Two have contract workers in the MHC process area.
- Six have other employees in the MHC process area.

MHC Line Operation. Potential for exposure during MHC line operation is expected to vary significantly among process methods. In manual, non-conveyorized methods, a line operator stands at the bath and manually lowers and raises the panel racks into and out of each bath. A vertical/automated method is completely automated, where panel racks are lowered and raised into vertical tanks by a robotic arm; line operators load and unload panels from the racks. A manually-controlled vertical hoist is a semi-automated system where racks are lowered into and raised out of a series of vertical chemical baths by a line operator-controlled hoist. The hoist is controlled by a hand-held control panel attached to the hoist by a cable. The conveyorized method is an automated method where panels are transported into and out of process baths by means of a conveyor; line operators load and unload panels from the conveyor system. Based on the workplace practices data:

- For electroless copper lines, 35 out of 36 are non-conveyorized, of which 19 are vertical/automated, ten are manually controlled vertical hoist, and six are manual (with no automation). One facility is conveyorized.
- All carbon and graphite lines in the database are conveyorized.
- The single conductive polymer system is conveyorized.
- The single non-formaldehyde electroless copper system is non-conveyorized, with manually controlled vertical hoist.
- For organic-palladium lines, one is conveyorized and one is non-conveyorized with a vertical/automated system.
- For tin-palladium lines, 13 are non-conveyorized, of which one is vertical/automated, four are manually controlled vertical hoist, and six are manual (no automation). Two facilities are conveyorized.

3.2 EXPOSURE ASSESSMENT

Different assumptions are made about worker exposure for non-conveyorized and conveyorized systems. For the non-conveyorized systems, it is assumed that workers manually lower and raise panel racks. This is a conservative but consistent assumption made for all non-conveyorized process alternatives.

Chemical Bath Sampling. Based on the questionnaire database, chemical baths in the carbon, graphite, and organic-palladium alternatives are normally sampled by use of a drain or spigot on the bath. For electroless copper, the most common method is to dip a container (ladle, beaker, or sample bottle) into a bath. For tin-palladium, the most common method reported is to sample by pipette.

Chemical Bath Additions. Methods of chemical additions from the database are as follows:

- Most facilities pour chemical additions directly into the bath or tank (63 percent).
- Other reported options include: stirring into a tank (24 percent), pouring into an automated chemical addition system (20 percent), or other (two percent). Stirring typically involves fluid agitation while pouring the formulation into the bath.
- For carbon and graphite facilities, 100 percent reported pouring directly into the tanks.

This activity is characterized for a model facility by pouring chemicals directly into the tank for all process alternatives except conductive polymer, where all additions are made automatically.

Chemical Bath Replacement. This process includes removing the spent bath, cleaning the empty tank, and making up fresh bath solutions. In this process, a worker could be exposed to chemicals in the spent bath, on the inside walls of the emptied bath, or to chemicals in the new bath solution.

Rack Cleaning. Rack cleaning only applies to those process alternatives where a buildup of material on the panel racks occurs (e.g., copper plating onto the racks). This includes the electroless copper, non-formaldehyde electroless copper, and tin-palladium processes. Rack cleaning for these processes could occur either as part of the routine MHC line operation (called “continuous” rack cleaning) or as a separate step in the process. Of the facilities responding to this question, only nine out of 36 electroless copper facilities and four out of 13 tin-palladium facilities reported rack cleaning as a separate step in the process. An additional 17 electroless copper facilities reported continuous rack cleaning. All of the remaining facilities reported the question was not applicable, did not respond, or gave an unusable response.

Because there were a low number of applicable or usable responses to the question, and a majority of the electroless copper facilities responding to the question use continuous rack cleaning, this activity is not considered quantitatively as a separate worker activity performed at a model facility.

Conveyor Equipment Cleaning. Conveyor equipment cleaning involves regular equipment maintenance for conveyorized MHC lines; 11 of the facilities in the database are conveyorized. Examples include cleaning the fluid circulation heads and rollers for the graphite process, and vacuuming particulates from the drying areas of graphite and carbon lines.

Filter Replacement. Filter replacement could result in exposure to the material on the filter or in the bath. Whether the pathway is significant to worker risk will depend, in part, on the chemical constituents in the bath.

Use of Personal Protective Equipment (PPE). An overview of the data pertaining to the use of PPE indicates the following general trends for the various activities:

- Most facilities reported the use of eye protection and gloves, but some did not.
- Use of lab coats or aprons was reported approximately 1/4 to 1/2 of the time.
- Few facilities reported using boots.
- The use of respiratory protection was very rarely reported.

It is assumed that the only PPE used is eye protection and that the line operator's hands and arms may contact bath solutions. This is a conservative but consistent assumption for all process alternatives and worker activities, particularly for dermal exposure. While most PWB facilities reported that line operators do wear gloves, the assumption that the line operator's hands and arms may contact bath solutions is intended to account for the fraction of workers who do not. For workers who do wear gloves, dermal contact exposure is expected to be negligible.

Summary of Scenarios. MHC Line Operators. In general, line operators perform several activities, including MHC line operation (which includes working in the MHC process area); chemical bath replacement; rack cleaning; conveyor equipment cleaning; filter replacement; chemical bath sampling; making chemical bath additions; and bail-out of baths. Some kind of local ventilation is typically used for the process line.

There are two different scenarios for line operators depending on process configuration. For non-conveyorized processes, dermal exposure could occur through routine line operation as well as bath maintenance activities. Inhalation exposure could occur throughout the time period a line operator is in the MHC process area. Conveyorized processes are enclosed and the line operator does not contact the bath solutions in routine line operation; he or she only loads panels at the beginning of the process and unloads them at the end of the process. For conveyorized processes, dermal exposure is primarily expected through bath maintenance activities such as bath replacement, bath sampling, and conveyor equipment cleaning. Because the conveyorized lines are enclosed and typically vented to the outside, inhalation exposure to line operators and other workers is assumed to be negligible for the conveyorized processes.

Laboratory Technicians. In general, laboratory technicians perform one activity pertaining to the MHC line, chemical bath sampling, in addition to working in the MHC process area. Bath sampling exposure is quantified separately for laboratory technicians.

Other Workers in the MHC Process Area. Other workers in the MHC process area may include maintenance workers, supervisory personnel, wastewater treatment operators, contract workers, and other employees. They perform activities not directly related to the MHC line, but typically spend some time in the MHC process area. Because the line operators spend the most amount of time per shift, exposure via inhalation is quantified for them (for non-conveyorized processes), and characterized for the other employees in terms of the time spent in the process area relative to line operators.

3.2.2 Selection of Exposure Pathways

The definition of exposure scenarios leads to selection of the exposure pathways to be evaluated. An exposure scenario may comprise one or several pathways. A complete exposure pathway consists of the following elements:

- A source of chemical and mechanism for release.
- An exposure point.
- A transport medium (if the exposure point differs from the source).
- An exposure route.

Tables 3.6 and 3.7 present an overview of the pathways selection for workplace and surrounding population exposures, respectively. For the workplace, another potential pathway not quantified is oral exposure to vapors or aerosols. For example, oral exposure could occur if inhaled chemicals are coughed up and then swallowed.

Population exposures may occur through releases to environmental media (i.e., releases to air, water, and land). The only pathway for which exposure is estimated is inhalation of chemicals released from a facility to a nearby residential area. Approaches for the three environmental media are described below.

Air

Air releases from the MHC process are modeled for the workplace. Those modeled emission rates are used in combination with an air dispersion model to estimate air concentrations to a nearby population.

Surface Water

Little reliable data are available for water releases for the MHC alternatives. (This issue is discussed further in Section 3.2.3.) Exposures and risks from surface water are evaluated qualitatively by identifying chemicals potentially released to surface water from the publicly-available bath chemistry data (discussed in Section 2.1.4), bath chemistry data for disclosed proprietary ingredients, and using ecological toxicity data to highlight those chemicals of highest ecological concern if released to surface water (Section 3.3).

Land

Possible sources of releases to land from MHC processes include bath filters and other solid wastes from the process line, chemical precipitates from baths, and sludge from wastewater treatment. These are discussed in Section 3.1, Source Release Assessment. Reliable characterization data for potential releases to land are not available; therefore, the exposure assessment does not estimate the nature and quantity of leachate from landfills or effects on groundwater.

Table 3.6 Workplace Activities and Associated Potential Exposure Pathways

Activities	Potential Pathways	Evaluation Approach and Rationale
Line Operators^a		
MHC Line Operation	Dermal contact with chemicals in MHC baths.	Exposure quantified for non-conveyorized lines; the highest potential dermal exposure is expected from this activity. Exposure for conveyorized lines assumed to be negligible for this activity.
	Inhalation of vapors or aerosols from MHC baths.	Exposure quantified for non-conveyorized lines. Exposure for conveyorized lines assumed to be negligible.
Working in Process Area	Inhalation of vapors or aerosols from MHC baths.	Exposure quantified for non-conveyorized lines.
Chemical Bath Replacement; Conveyor Equipment Cleaning; Filter Replacement; Chemical Bath Sampling	Dermal contact with replacement chemicals.	Exposure quantified for conveyorized lines for all activities together (bath sampling quantified separately for laboratory technicians). Exposure not quantified separately for these activities on non-conveyorized lines.
	Inhalation of vapors or aerosols from MHC baths.	Not quantified separately. Included in “working in process area” for non-conveyorized lines; not quantified due to modeling limitations for conveyorized lines.
Rack Cleaning	Dermal contact with chemicals on racks.	Not quantified; limited data indicate this is not performed by many facilities.
	Inhalation of vapors or aerosols from MHC baths.	Not quantified separately. Included in “working in process area” for non-conveyorized lines; not quantified due to modeling limitations for conveyorized lines.
Chemical Bath Additions	Dermal contact with chemicals added.	Not quantified separately from chemicals already in the baths.
	Inhalation of vapors or aerosols from MHC baths or while making bath additions.	Not quantified separately. Included in “working in process area” for non-conveyorized lines; not quantified due to modeling limitations for conveyorized lines.
Laboratory Technicians		
Chemical Bath Sampling	Dermal contact with chemicals in MHC baths.	Exposure quantified for conveyorized and non-conveyorized lines.
	Inhalation of vapors or aerosols from MHC baths.	Not quantified separately (included in “working in process area”).
Working in Process Area	Inhalation of vapors or aerosols from MHC baths.	Exposure quantified for line operators for non-conveyorized lines; exposure for other workers is proportional to their exposure durations.

3.2 EXPOSURE ASSESSMENT

Activities	Potential Pathways	Evaluation Approach and Rationale
Maintenance Workers, Supervisory Personnel, Wastewater Treatment Operators, Contract Workers, and Other Workers		
Working in Process Area	Inhalation of vapors or aerosols from MHC baths.	Exposure quantified for line operators for non-conveyorized lines; exposure for other workers is proportional to their exposure durations.
	Dermal contact with chemicals in MHC baths.	Not quantified. ^a

^a This assumes MHC line operators are the most exposed individuals and perform all direct maintenance on the MHC line, including filter replacement and equipment cleaning.

Table 3.7 Potential Population Exposure Pathways

Population	Potential Pathways	Evaluation Approach and Rationale
Residents Living Near a PWB Facility	Inhalation of chemicals released to air.	Exposure quantified for all potential carcinogens and any other chemical released at a rate of at least 23 kg/year.
	Contact with chemicals released to surface water directly or through the food chain.	Not evaluated.
	Exposure to chemicals released to land or groundwater.	Not evaluated.
Ecological	Exposure to chemicals released to surface water.	Evaluated qualitatively in the Human Health and Ecological Hazards Summary (Section 3.3).
	Exposure to chemicals released to air or land.	Not evaluated.

3.2.3 Exposure-Point Concentrations

The term exposure-point concentration refers to a chemical concentration in its transport or carrier medium, at the point of contact (or potential point of contact) with a human or environmental receptor. Sources of data for the Exposure Assessment include monitoring data, publicly-available bath chemistry data, some proprietary bath chemistry data, and fate and transport models to estimate air releases and air concentrations. Concentrations for dermal exposure in the baths are those estimated from publicly-available bath chemistry data, as described in Section 2.1.4, and from disclosed proprietary ingredient information. Fate and transport modeling were performed to estimate air concentrations for workplace and surrounding population exposures as described in this section.

Monitoring Data

Table 3.8 presents a summary of all available Federal Occupational Safety and Health Administration (OSHA) data for PWB manufacturers (standard industrial code [SIC] 3672). California OSHA was also consulted for monitoring data; they referred to the Federal OSHA database. In addition, one facility submitted results of monitoring for formaldehyde at 0.06 ppm (8 hr. time-weighted average [TWA]) along with their response to the IPC Workplace Practices Questionnaire.

It should be noted that OSHA monitoring is typically performed only for those chemicals which are regulated by OSHA (i.e., chemicals with permissible exposure limits [PELs]). Monitoring also does not distinguish between the MHC process and other parts of the PWB process that may be located in the same area.

Table 3.8 Summary of Federal OSHA Monitoring Data for PWB Manufacturers (SIC 3672)

Chemical	No. of Data Points/ No. of Facilities	Range (ppm)	Average (ppm) ^a	Standard Deviation (ppm)
Ammonia	26 / 6	0 - 27	6.9	8.24
Copper Sulfate, as Copper	11 / 2	0 - 0	0	0
Ethanolamine	5 / 1	0 - 0.09	0.02	0.04
Formaldehyde	43 / 11	0 - 4.65	0.44	0.75
Hydrochloric Acid	26 / 5	0 - 0	0	0
Isopropanol	16 / 4	0 - 215	41.7	57.6
Methanol	6 / 1	0 - 0	0	0
Phosphoric Acid	3 / 1	0 - 0	0	0
Sodium Hydroxide	33 / 6	0 - 2.3	0.359	0.614
Stannous Chloride, as Tin	26 / 10	0 - 0.113	0.006	0.023
Sulfuric Acid	28 / 11	0 - 0.24	0.045	0.070

^a Zeros were included in averages; detection limits were not reported.

Modeling Workplace Air Concentrations

Bath concentrations estimated from publicly-available chemistry data and disclosed proprietary chemical data, as well as process configurations from the IPC Workplace Practices Questionnaire, were used to estimate workplace and ambient air concentrations using fate and transport models (Robinson et al., 1997). This section describes air transport models to estimate worker inhalation exposure to chemicals from PWB MHC lines. Three air transport models are used to estimate worker exposure:

1. Volatilization of chemicals induced by air sparging.
2. Aerosol generation induced by air sparging.
3. Volatilization of chemicals from the open surface of MHC tanks.

For models 1 and 3, volatilization was modeled only for those chemicals with a vapor pressure above 10^{-3} torr (a vapor pressure less than 10^{-3} torr was assumed for inorganic salts even if vapor pressure data were not available). Aerosol generation and volatilization from air-sparged baths were modeled only for those baths that are mixed by air sparging as indicated in the Workplace Practices and Performance Demonstration data; this includes the electroless copper baths and some cleaning tanks. The total transport of chemicals from the air-sparged baths was determined by summing the releases from each of the three models. The third model was applied to determine volatilization of chemicals from un-sparged baths. A review of the relevant literature, descriptions of the models, and examples demonstrating the use of the models are available in the December 22, 1995 Technical Memorandum, *Modeling Worker Inhalation*

3.2 EXPOSURE ASSESSMENT

Exposure (Appendix D). Modeled emission rates and workplace air concentrations are presented in Table 3.9. Proprietary chemical results are not presented in order to protect proprietary chemical identities.

Table 3.9 Results of Workplace Air Modeling

Chemical ^a	Emission Rate (mg/min)	Air Conc. (mg/m ³)	Federal OSHA and/or NIOSH Permissible Inhalation Exposure Limits (mg/m ³) ^b
Electroless Copper, non-conveyorized			
Ammonium Chloride	NA	NA	10 (NIOSH)
Benzotriazole	1.24e-01	5.54e-03	
Boric Acid	1.71e-01	7.64e-03	
Copper (I) Chloride	7.56e-02	3.38e-03	1 (as Cu dust and mist; OSHA/NIOSH)
Copper Sulfate; or Cupric Sulfate	8.31e-02	3.71e-03	1 (as Cu dust and mist; OSHA/NIOSH)
Dimethylaminoborane	1.94e+00	8.66e-02	
Dimethylformamide	1.42e+00	6.33e-02	30 (OSHA/NIOSH)
2-Ethoxyethanol	1.46e+03	6.51e+01	740 (OSHA); 1.8 (NIOSH)
Ethanolamine	9.92e+00	4.44e-01	6 (OSHA)
Ethylene Glycol	3.33e+00	1.49e-01	
Ethylenediaminetetraacetic Acid (EDTA)	5.11e-01	2.29e+02	
Fluoroboric Acid	2.20e+00	9.82e-02	
Formaldehyde	1.37e+01	6.15e-01	0.94 (0.75 ppm) ^c (OSHA)
Formic Acid	3.51e+01	1.57e+00	9 (OSHA/NIOSH)
Hydrochloric Acid	5.43e-03	2.43e-04	7 (NIOSH)
Hydrogen Peroxide	1.66e-01	7.41e-03	1.4 (OSHA/NIOSH)
Hydroxyacetic Acid	3.14e-02	1.40e-03	
Isopropyl Alcohol; or 2-Propanol	5.24e+02	2.34e+01	980 (OSHA)
m-Nitrobenzene Sulfonic Acid	9.14e-04	4.09e-05	
Magnesium Carbonate	9.99e-03	4.47e-04	
Methanol	2.31e+02	1.03e+01	260 (OSHA/NIOSH)
p-Toluene Sulfonic Acid	NA	NA	
Palladium	NA	NA	
Peroxymonosulfuric Acid	2.15e-01	9.60e-03	
Potassium Bisulfate	1.15e-01	5.14e-03	
Potassium Cyanide	2.52e-03	1.13e-04	5 (as CN; OSHA/NIOSH)
Potassium Hydroxide	2.33e-03	1.04e-04	2 (NIOSH)
Potassium Persulfate	8.16e-02	3.65e-03	
Potassium Sulfate	1.60e-01	7.15e-03	
Potassium-Sodium Tartrate	3.55e-01	1.59e-02	
Sodium Bisulfate	NA	NA	
Sodium Carbonate	5.65e-04	2.53e-05	

Chemical ^a	Emission Rate (mg/min)	Air Conc. (mg/m ³)	Federal OSHA and/or NIOSH Permissible Inhalation Exposure Limits (mg/m ³) ^b
Sodium Chlorite	NA	NA	
Sodium Cyanide	2.61e-03	1.17e-04	5 (as CN; OSHA/NIOSH)
Sodium Hydroxide	1.18e-01	5.26e-03	2 (OSHA/NIOSH)
Sodium Hypophosphite	NA	NA	
Sodium Sulfate	NA	NA	
Stannous Chloride	NA	NA	2 (as Sn; OSHA)
Sulfuric Acid	1.24e+00	5.57e-02	1 (OSHA)
Tartaric Acid	1.17e-02	5.21e-04	
Triethanolamine; or 2,2',2''-Nitrilotris Ethanol	NA	NA	
Non-Formaldehyde Electroless Copper, non-conveyorized			
Copper Sulfate; or Cupric Sulfate	2.74e-01	1.22e-02	1 (as Cu dust and mist; OSHA/NIOSH)
Hydrochloric Acid	NA	NA	7 (NIOSH)
Hydrogen Peroxide	9.36e-02	4.19e-03	1.4 (OSHA/NIOSH)
Isopropyl Alcohol; or 2-Propanol	7.34e+01	3.28e+00	980 (OSHA)
Potassium Hydroxide	1.49e-03	6.67e-05	2 (NIOSH)
Potassium Persulfate	5.68e-02	2.54e-03	
Sodium Chlorite	NA	NA	
Sodium Hydroxide	1.74e-03	7.78e-05	2 (OSHA/NIOSH)
Stannous Chloride	NA	NA	2 (as Sn; OSHA)
Sulfuric Acid	1.48e-01	6.63e-03	1 (OSHA)
Organic-Palladium, non-conveyorized			
Hydrochloric Acid	NA	NA	7 (NIOSH)
Sodium Bisulfate	NA	NA	
Sodium Carbonate	NA	NA	
Sodium Hypophosphite	NA	NA	
Sodium Persulfate	NA	NA	
Trisodium Citrate 5.5-Hydrate; or Sodium Citrate	NA	NA	
Tin-Palladium, non-conveyorized			
1,3-Benzenediol	NA	NA	
Copper (I) Chloride	NA	NA	1 (as Cu dust and mist; OSHA/NIOSH)
Copper Sulfate; or Cupric Sulfate	7.38e-02	3.30e-03	1 (as Cu dust and mist; OSHA/NIOSH)
Ethanolamine	2.00e+01	8.92e-01	6 (OSHA)
Fluoroboric Acid	1.76e+00	7.89e-02	
Hydrochloric Acid	NA	NA	7 (NIOSH)
Hydrogen Peroxide	9.71e-02	4.34e-03	1.4 (OSHA/NIOSH)
Isopropyl Alcohol; or 2-Propanol	2.94e+02	1.32e+01	980 (OSHA)

3.2 EXPOSURE ASSESSMENT

Chemical ^a	Emission Rate (mg/min)	Air Conc. (mg/m ³)	Federal OSHA and/or NIOSH Permissible Inhalation Exposure Limits (mg/m ³) ^b
Lithium Hydroxide	NA	NA	
Palladium	NA	NA	
Palladium Chloride	NA	NA	
Potassium Carbonate	NA	NA	
Sodium Bisulfate	NA	NA	
Sodium Chloride	NA	NA	
Sodium Hydroxide	NA	NA	2 (OSHA/NIOSH)
Sodium Persulfate	8.38e-01	3.75e-02	
Stannous Chloride	NA	NA	2 (as Sn; OSHA)
Sulfuric Acid	1.16e-01	5.19e-03	1 (OSHA)
Triethanolamine; or 2,2',2''-Nitrilotris Ethanol	NA	NA	
Vanillin	8.09e-02	3.62e-03	

^a Proprietary chemical results are not presented in order to protect proprietary chemical identities.

^b Source: NIOSH, 1994 and 29 CFR 1910.1000, Table Z-1.

^c OSHA has set an “action level” of 0.5 ppm for formaldehyde. At or above that level, people working in the area of exposure must be monitored, and the area must be segregated. From 0.1 - 0.5 ppm, workers must be notified that formaldehyde is present (but not that it is suspected of being a carcinogen).

NA: Not Applicable. A number was not calculated because the chemical’s vapor pressure is below the 1×10^{-3} torr cutoff and is not used in any air-sparged bath. Therefore, air concentrations are expected to be negligible.

Note: The numeric format used in these tables is a form of scientific notation, where the “e” replaces the “ $\times 10^x$ ” in scientific notation. Scientific notation is typically used to present very large or very small numbers. For example, $1.2\text{e-}04$ is the same as 1.2×10^{-4} , which is the same as 0.00012 in common decimal notation.

Volatilization of Chemicals from Air-Sparged MHC Tanks. Mixing in plating tanks (e.g., the electroless copper plating tank) is commonly accomplished by sparging the tank with air. The equation used for predicting the mass transfer rate from an aerated system is based on volatilization models used in research of aeration in wastewater treatment plants:

$$F_{y,s} = Q_G H_y c_{L,y} \left[1 - \exp \left(- \frac{K_{OL,y} a V_L}{H_y Q_G} \right) \right]$$

where:

- $F_{y,s}$ = mass transfer rate of chemical y out of the system by sparging (mg/min)
- Q_G = gas flow rate (L/min)
- H_y = dimensionless Henry’s Law Constant (H_C) for chemical y
- $c_{L,y}$ = concentration of chemical y in bulk liquid (mg/L)
- $K_{OL,y}$ = overall mass transfer coefficient for chemical y (cm/min)
- a = interfacial area of bubble per unit volume of liquid (cm²/cm³)
- V_L = volume of liquid (cm³)

Aerosol Generation from Baths Mixed by Sparging with Air. Aerosols or mists are also a potential source of contaminants from electroless baths. The rate of aerosol generation has been found to depend on the air sparging rate, bath temperature, air flow rate above the bath, and

the distance between bath surface and the tank rim. The following equation is used to estimate the rate of aerosol generation (Berglund and Lindh, 1987):

$$R_A = [5.5 \times 10^{-5} (Q_G / A) + 0.01] F_T F_A F_D$$

where:

- R_A = aerosol generation rate (ml/min/m²)
- Q_G = air sparging rate (cm³/min)
- A = bath area (m²)
- F_T = temperature correction factor
- F_A = air velocity correction factor
- F_D = distance between the bath surface and tank rim correction factor.

The emission of contaminants resulting from aerosols depends on both the rate of aerosol generation and the concentration of contaminants in the aerosol. The following equation is used to estimate contaminant emission (flux) from aerosol generation:

$$F_{y,a} = \frac{M_I}{M_b} f_{IE} F_{y,s}$$

where:

- $F_{y,a}$ = rate of mass transfer from the tank to the atmosphere by aerosols (mg/min)
- f_{IE} = fraction of bubble interface ejected as aerosols (dimensionless)
- M_I = mass of contaminant at the interface (mg)
- M_b = mass of contaminant in gas bubble (mg)

The literature on aerosol generation indicates that the typical size of aerosols is one to ten microns; this is important to note because particles in this range are more inhalable. Larger sized particles tend to fall back into baths rather than remaining airborne and dispersing throughout the room.

Volatilization of Chemicals from the Open Surface of MHC Tanks. Most plating tanks have a free liquid surface from which chemicals can volatilize into the workplace air. Air currents across the tank will accelerate the rate of volatilization. The EPA's Chemical Engineering Branch (CEB) Manual (EPA, 1991a) suggests the following model for evaporation of chemicals from open surfaces:

$$F_{y,o} = 1200 c_{L,y} H_y A [D_{y,air} v_z / (\pi z)]^{0.5}$$

where:

- $F_{y,o}$ = volatilization rate of chemical y from open tanks (mg/min)
- $c_{L,y}$ = concentration of chemical y in bulk liquid (mg/L)
- H_y = dimensionless Henry's Law Constant (H_c) for chemical y
- $D_{y,air}$ = molecular diffusion coefficient of chemical y in air (cm²/sec)
- v_z = air velocity (m/sec)
- z = distance along the pool surface (m)
- A = bath area (m²)

3.2 EXPOSURE ASSESSMENT

Some limitations of the model should be pointed out. The model was developed to predict the rate of volatilization of pure chemicals, not aqueous solutions. The model was also derived using pure chemicals. As a result, the model implicitly assumes that mass transfer resistance on the gas side is the limiting factor. The model may overestimate volatilization of chemicals from solutions when liquid-side mass transfer is the controlling factor.

Calculation of Chemical Concentration in Workplace Air from Emission Rates. The indoor air concentration is estimated from the following equation (EPA, 1991a):

$$C_y = F_{y,T}/(V_R R_V k)$$

where:

C_y	=	workplace contaminant concentration (mg/m ³)
$F_{y,T}$	=	total emission rate of chemical from all sources (mg/min)
V_R	=	room volume (m ³)
R_V	=	room ventilation rate (min ⁻¹)
k	=	dimensionless mixing factor

The mixing factor accounts for slow and incomplete mixing of ventilation air with room air. A value of 1.0 was used for this factor. The CEB Manual commonly uses values of the ventilation rate Q from 500 ft³/min to 3,500 ft³/min. Ventilation rates for MHC lines were determined from the facility data. An air turnover rate of 0.021 per minute (1.26 per hour) was used, which is based on estimated air turnover rates that yield 90th percentile air concentrations from Monte Carlo analysis. (This is explained in detail in Appendix D.) An average room volume was used from questionnaire data assuming a ten foot room height.

Other assumptions pertaining to these air models include the following:

- Deposition on equipment, condensation of vapors, and photodegradation are negligible.
- Incoming air is contaminant-free.
- The concentration of contaminant at the beginning of the day is zero.
- As much air enters the room as exits through ventilation (mass balance).
- Room air and ventilation air mix ideally.

Sensitivity Analysis. Model sensitivity and uncertainty was examined using Monte Carlo analysis with the air transport equations outlined above and probability distributions for each parameter based on data from the IPC Workplace Practices Questionnaire (see Appendix D for details). This was done with a Monte Carlo software package (Crystal Ball™ [Decisioneering, Inc., 1993]) in conjunction with a spreadsheet program.

This analysis suggested that a few parameters are key to modeling chemical flux from PWB tanks. These key parameters are air turnover rate, bath temperature, chemical concentration in the bath, and Henry's Law Constant.

The air model's sensitivity to these parameters and their uncertainty provides a means of isolating them from less important variables. Isolating these variables allows for additional

scrutiny to be placed upon the point estimate assumptions used for them in the volatilization models.

The air turnover rate assumption contributes most to overall model variance. The chemical bath concentration and bath temperature also contribute variance to the model, but are less important than air turnover rate. This statement is fortified by the fact that relatively accurate information is available on their distributions. H_C appears to be least important of the four, but may have more variability associated with it. The models appear to be largely indifferent to small changes in most other parameters.

Modeling Air Concentrations for Population Exposure

The following approach was used for dispersion modeling of air emissions from a single facility:

- Model: Industrial Source Complex Long Term ISC(2)LT model from the Risk*Assistant™ software.
- Building (release) height: 3m.
- Area source: 10 x 10 m.
- Meteorological data: an average emission rate-to-air concentration factor of 2.18×10^{-6} min/m³ was determined using data for Oakland, California; Denver, Colorado; and Phoenix, Arizona. (These three areas give the highest modeled concentrations around a facility for any available city data in the model.)
- Other parameters: regulatory default values were used. (These are model defaults pertaining to plume rise, stack-tip downwash, buoyancy-induced dispersion, wind profile exponents, vertical temperature gradient, and buildings adjacent to the emission source.)
- Setting: urban mode. (The setting can be either rural or urban. The urban setting is appropriate for urban areas or for large facilities.)
- Chemical degradation in air: not included in modeling.
- Location for exposure point concentrations: a standard polar grid³ with 36 vector directions and one distance ring (at 100m) was used; the highest modeled air concentration in any direction at 100 meters was used to estimate population exposure.

Because of the short time expected for chemical transport to nearby residents, chemical degradation is not taken into account. The emission rates calculated for workplace inhalation exposures are used for the source emission rates to ambient air. Ambient air concentrations were not modeled for those chemicals with facility emission rates less than 23 kg/year (44 mg/min), with the exception of formaldehyde, which was included because it is a potential carcinogen. Results of ambient air modeling are presented in Table 3.10. Proprietary chemical results are not presented to protect proprietary chemical identities.

³ A polar grid is a coordinate system that describes the location of a point by means of direction and distance in relation to a central point (e.g., two miles northeast of the center). In the model, a series of regularly-spaced concentric distance rings are defined at chosen intervals along with a defined number of direction vectors (e.g., north, south, east, west, northeast, northwest, southeast, and southwest would be eight directions).

Table 3.10 Results of Ambient Air Modeling

Chemical^a	Emission Rate^b (mg/min)	Air Conc. (mg/m³)
Electroless Copper, non-conveyorized		
2-Ethoxyethanol	1.46e+03	3.17e-03
Formaldehyde	1.37e+01	3.00e-05
Isopropyl Alcohol; or 2-Propanol	5.24e+02	1.14e-03
Methanol	2.31e+02	5.03e-04
Electroless Copper, conveyorized		
2-Ethoxyethanol	1.55e+03	3.38e-03
Formaldehyde	3.66e+01	7.97e-05
Formic Acid	7.90e+01	1.72e-04
Isopropyl Alcohol; or 2-Propanol	1.04e+03	2.26e-03
Methanol	4.28e+02	9.34e-04
Non-Formaldehyde Electroless Copper, non-conveyorized		
Isopropyl Alcohol; or 2-Propanol	7.34e+01	1.60e-04
Tin-Palladium, non-conveyorized		
Isopropyl Alcohol; or 2-Propanol	2.94e+02	6.42e-04
Tin-Palladium, conveyorized		
Ethanolamine	5.23e+01	1.14e-04
Isopropyl Alcohol; or 2-Propanol	2.34e+02	5.11e-04

^a Proprietary chemical results are not presented in order to protect proprietary chemical identities.

^b Only those chemicals with an emission rate at least 23 kg/year (44 mg/min), plus formaldehyde, are listed.

Carbon, conductive polymer, graphite, and organic-palladium had no modeled emission rates above this cut-off.

Note: The numeric format used in these tables is a form of scientific notation, where the “e” replaces the “x 10^{xx}” in scientific notation. Scientific notation is typically used to present very large or very small numbers. For example, 1.2e-04 is the same as 1.2 x 10⁻⁴, which is the same as 0.00012 in common decimal notation.

Surface Water

Environmental releases to surface water were not quantified because chemical constituents and concentrations in wastewater could not be adequately characterized for the MHC line alone. This is because PWB manufacturers typically combine wastewater effluent from the MHC process line with effluent from other PWB manufacturing processes prior to on-site wastewater pretreatment. The pretreated wastewater is then discharged to a POTW. Many PWB manufacturers measure copper concentrations in effluent from on-site pretreatment facilities in accordance with POTW discharge permits, but they do not measure copper concentrations in MHC line effluent prior to pretreatment. Because there are many sources of copper-contaminated wastewater in PWB manufacturing, the contribution of the MHC line to overall copper discharges could not be estimated. Furthermore, most of the MHC alternatives contain copper, but because these technologies are only now being implemented in the U.S., their influence on total copper discharges from a PWB facility cannot be determined. Finally, while data are available on copper discharges from PWB facilities, data are not available for some of the other metals found in alternatives to electroless copper. Although ecological hazards are assessed in Section 3.3, without exposure or release data ecological risk could not be addressed

in the risk characterization.

3.2.4 Exposure Parameters and Potential Dose Rate Models

This section contains information on models and parameter values for workplace and population exposure estimates. First, more detailed data from the IPC Workplace Practices Questionnaire are presented, then the exposure models and parameter values used in those models are described.

Workplace Exposure Parameter Values

Data on the frequency and duration of activities indicate the amount of time a worker may be exposed through workplace activities. Questionnaire data pertaining to various worker activities follow.

Line Operation. The time per shift that an MHC line operates gives an indication of the daily exposure duration associated with line operation. Time per shift varies by process type and degree of automation. It is probably also influenced by the total amount of PWB processed at a facility and MHC line capacity. Because limited data do not allow differentiation between MHC line operation needs for the various process alternatives, the same period of time for line operation is assumed for all process alternatives. This time, for all processes, ranges from one to 12 hours per shift, with an average of 6.8 hours per shift and a 90th percentile value of eight hours per shift.

Chemical Bath Sampling. Table 3.11 presents questionnaire data pertaining to duration and frequency of chemical bath sampling. These parameters are assumed to vary by MHC technology, but not by equipment configuration (e.g., non-conveyorized or conveyorized).

Chemical Additions. Table 3.12 presents questionnaire and supplier data pertaining to duration and frequency of chemical additions. Duration data indicate the amount of time a worker may be exposed to the chemicals being added to the bath. Although duration data vary by process and bath type, greater variation may be due to differences in facility operating procedures than differences inherent to process alternatives. Therefore, the same duration is assumed for all facilities, regardless of process, equipment, or bath type. Frequency of chemical additions was determined from supplier-provided data, typically a supplier's Product Data Sheet, which recommends a schedule for chemical additions based on time, amount of PWB (ssf) processed, or bath concentrations determined through sampling. For the purposes of this assessment, schedules based on time or ssf of PWB processed were used.

Chemical Bath Replacement. Table 3.13 presents questionnaire data pertaining to duration of chemical bath replacement. Questionnaire data were combined regardless of process configuration for replacement duration. Bath replacement frequency for conveyorized lines was determined specifically for type of bath. The 90th percentile frequencies are presented in Table 3.14.

3.2 EXPOSURE ASSESSMENT

Table 3.11 Duration and Frequency of Chemical Bath Sampling

Process Alternative (number responding) ^a	Duration of Sampling (minutes)		Frequency of Sampling (occur./year)		Total Responses for All Baths
	Average ^b	90th Percentile	Average ^b	90th Percentile	
Electroless Copper (32)	0.44 - 5.4	3	217 - 996	720	212
Carbon (2)	2.0	2	220	220	8
Conductive Polymer (1)	1.0	1	100 - 460	414	3
Graphite (4)	1.0 - 5.5	10	213 - 255	260	13
Non-Formaldehyde Electroless Copper (1)	1.0	1	50 - 260	260	5
Organic-Palladium (2)	1.5 - 2	2	230 - 490	250	13
Tin-Palladium (12)	1.2 - 4.0	2	210 - 660	520	65

^a Five facilities did not respond to this question.

^b Range of averages for each bath type.

Table 3.12 Duration and Frequency of Chemical Additions

Facility Type	Duration of Chemical Additions (minutes) ^a		Frequency of Chemical Additions (times/year) ^b
	Average	90th Percentile	
Electroless Copper	3.6 - 10 ^c	ND	0.4 - 52 ^c
Carbon	2 - 10 ^c	ND	1 - 58 ^c
Graphite	2 - 19 ^c	ND	4 - 44 ^c
Non-Formaldehyde Electroless Copper	2, regardless of bath type	ND	
Organic-Palladium	20 - 25 ^c	ND	11 - 52 ^c
Tin-Palladium	5 - 15 ^c	ND	0.7 - 12 ^c
All Facilities, regardless of process type	8.6	20	ND

^a From IPC Workplace Practices Questionnaire and Performance Demonstration database.

^b Based on supplier-provided information.

^c Depending on bath type.

ND: Not Determined.

Table 3.13 Duration of Chemical Bath Replacement

Process Alternative (number responding)	Duration (minutes)		
	Average ^a	90th Percentile	Total Responses for All Baths
Electroless Copper (36)	41 - 147	180	205
Carbon (2)	15 - 180	180	8
Conductive Polymer (1)	60 - 240	228	3
Graphite (3)	18 - 240	219	10
Non-Formaldehyde Electroless Copper (1)	30	30	5
Organic-Palladium (2)	30 - 360	108	13
Tin-Palladium (13)	31 - 110	180	75
All Facilities	78	ND	350

^a Range of averages for each bath type.

ND: Not Determined.

Table 3.14 Frequency of Chemical Bath Replacement for Conveyorized Processes

Process Alternative	Bath Type	90th Percentile Frequency (occur./year)	Bath Type	90th Percentile Frequency (occur./year)
Electroless Copper	Conditioner/Cleaner	24	Accelerator	16
	Microetch	50	Electroless	4
	Predip	24	Copper	50
	Catalyst	1	Acid Dip	28
			Anti-Tarnish	
Carbon	Cleaner	30	Carbon Black	1
	Conditioner	30	Microetch	145
Conductive Polymer	Microetch	20.5	Catalyst	1
	Cleaner/Conditioner	13	Conductive Polymer	17
Graphite	Cleaner/Conditioner	56	Microetch	145
	Graphite	7.3		
Organic-Palladium	Conditioner	32	Conductor	1
	Microetch	1	Post-Dip	20
	Predip	230		
Tin-Palladium	Cleaner/Conditioner	141	Accelerator	47
	Predip	151	Microetch	65
	Catalyst	1	Acid Dip	230

Conveyor Equipment Cleaning. For conveyor equipment cleaning, nine facilities responded out of a total of 11 conveyorized systems. For these facilities:

- Duration of conveyor equipment cleaning ranged from 0.5 to 480 minutes, with an average of 140 minutes and 90th percentile of 288 minutes.
- Frequency of conveyor equipment cleaning ranged from two to 260 times per year, with an average of 55 times per year and 90th percentile of 92 times per year.

Bath Filter Replacement. Table 3.15 presents data on duration and frequency of bath filter replacement. For filter replacement, depending on bath and process types, the average duration ranges from one to 31 minutes and the average frequency ranges from 12 to 300 times per year. The frequency data used for intake model parameters is process-specific. Again, the duration for all facilities is assumed, regardless of process alternative or bath type.

Working in the Process Area. Table 3.16 presents questionnaire data pertaining to the amount of time various types of workers spend working in the MHC process area. Frequency is considered to be the days/year the MHC line is in operation (an average of 250 days/year and 90th percentile of 306 days/year).

Table 3.15 Filter Replacement

Process Alternative (number responding) ^a	Duration (minutes)		Total Responses for All Baths	Frequency (occur./year)		Total Responses for All Baths
	Average ^b	90th Percentile		Average ^b	90th Percentile	
Electroless Copper (20)	8 - 31	ND	82	37 - 200	100	76
Carbon (2)	5	ND	6	12 - 20	20	6
Conductive Polymer (1)	5 - 10	ND	4	12.5 - 115	74	4
Graphite (4)	7 - 10	ND	9	67 - 107	103	9
Non-Formaldehyde Electroless Copper (1)	1 - 5	ND	2	16.7	17	2
Organic-Palladium (2)	2 - 3.5	ND	10	12 - 38	50	10
Tin-Palladium (3)	5 - 11	ND	14	24 - 300	74	14
All Facilities	13	20	138	ND	ND	138

^a Sixteen facilities did not respond to this question.

^b Range of averages for each bath type.

ND: Not Determined.

Table 3.16 Duration of Working in the Process Area

Worker Type	Range (hours/shift)	Average (hours/shift)	90th Percentile (hours/shift)
Line Operators	3.3 - 10	7.8	8
Laboratory Technicians	0.1 - 10	3.9	8
Maintenance Workers	0.15 - 10	3.1	8
Supervisory Personnel	0.23 - 10	4.7	8
Wastewater Treatment Operators	0.1 - 10	4.4	8
Contract Workers	0.25	0.25	0.25
Other Employees	0.18 - 8	3.4	5.6

Workplace Exposure Models

The general models for calculating inhalation and dermal potential dose rates are discussed below.

Daily Inhalation Exposures. The general model for inhalation exposure to workers is from CEB (EPA, 1991a):

$$I = (C_m)(b)(h)$$

where:

- I = daily inhalation potential dose rate (mg/day)
- C_m = airborne concentration of substance (mg/m³) (note: this term is denoted “C_y” in air modeling equation in Section 3.2.3)
- b = inhalation rate (m³/hr)
- h = duration (hr/day)

Data for these parameters are in Table 3.17.

Table 3.17 Parameter Values for Daily Workplace Inhalation Exposures

Parameter	Units	Value	Source of Data, Comments
Cm	mg/m ³	Modeled from single or average bath concentrations	
b	m ³ /hr	1.25	EPA, 1991a (data from NIOSH, 1976).
Duration (h)			
Line Operation	hours/day	8	From IPC Workplace Practices Questionnaire, 90th percentile for hours of MHC line operation, all process types (assuming hours/shift = hours/day).
Working in Process Area	hours/day	8	From IPC Workplace Practices Questionnaire, 90th percentile for hours/shift for first shift, all process types.

Daily Workplace Dermal Exposures. The general model for potential dose rate via dermal exposure to workers is from CEB (EPA, 1991a):

$$D = SQC$$

where:

- D = dermal potential dose rate (mg/day)
- S = surface area of contact (cm²)
- Q = quantity typically remaining on skin (mg/cm²)
- C = concentration of chemical (percent)

Because a line operator is expected to have dermal contact with the chemicals in a given bath several times a day in the course of normal operations, the total time of contact combined with a flux rate (rate of chemical absorption through the skin) is believed to give a more realistic estimate of dermal exposure. The flux of a material through the skin is estimated in terms of mg absorbed per cm² per unit of time. Using flux of material through the skin, (based on EPA, 1992a) the equation is modified to:

$$D = (S)(C)(f)(h)(0.001)$$

where:

- D = dermal potential dose rate (mg/day)
 - S = surface area of contact (cm²)
 - C = concentration of chemical (mg/L)
 - f = flux through skin (cm/hour)
 - h = duration (hours/day)
- with a conversion factor of 0.001 L/cm³

This second equation was used for all workplace dermal exposure estimates.

Data for duration of contact (h) from the IPC Workplace Practices Questionnaire are included in Table 3.18.

3.2 EXPOSURE ASSESSMENT

Table 3.18 Parameter Values for Daily Workplace Dermal Exposures

Parameter	Units	Value		Source of Data, Comments
C	%	Range of reported values and average determined from publicly-available chemistry data and from disclosed proprietary ingredient information (see Section 2.1.4 and Appendix B).		
S	cm ²	1,300		CEB Table 4-13, routine immersion, 2 hands, assuming gloves not worn.
Flux Through Skin (f)	cm/hr	Default for inorganics: 0.001 estimate for organics by: log f = -2.72+0.71 log K _{ow} -0.0061(MW) (K _{ow} = octanol/water partition coefficient, MW = molecular weight)		EPA, 1992a.
Duration of Contact (h)				
Line Operation	hours/day	8		90th percentile from IPC Workplace Practices Questionnaire, hours of MHC line operation, all process types excluding conveyORIZED processes.
		<i>electroless copper</i> (19 baths)	0.42	Corrected for typical number of baths in a process, including rinse baths.
		<i>non-formaldehyde electroless copper</i> (17 baths)	0.47	
		<i>organic-palladium</i> (12 baths)	0.67	
		<i>tin-palladium</i> (14 baths)	0.57	
Chemical Bath Replacement	min/occur	<i>carbon</i>	180	90th percentile from IPC Workplace Practices Questionnaire.
		<i>conductive polymer</i>	228	
		<i>electroless copper</i>	180	
		<i>graphite</i>	219	
		<i>non-formaldehyde electroless copper</i>	30	
		<i>organic-palladium</i>	108	
		<i>tin-palladium</i>	180	
Conveyor Equipment Cleaning	min/occur	288		90th percentile from IPC Workplace Practices Questionnaire, conveyORIZED lines.
Filter Replacement	min/occur	20		90th percentile from IPC Workplace Practices Questionnaire, all process types.
Chemical Bath Sampling	min/occur	<i>carbon</i>	2	90th percentile from IPC Workplace Practices Questionnaire, excluding automated sampling.
		<i>conductive polymer</i>	1	
		<i>electroless copper</i>	5	
		<i>graphite</i>	10	
		<i>non-formaldehyde electroless copper</i>	1	
		<i>organic-palladium</i>	2	
		<i>tin-palladium</i>	2	

Daily exposures are averaged over a lifetime (70 years) for carcinogens, and over the exposure duration (e.g., 25 years working in a facility) for non-carcinogens⁴ using the following equations. To estimate average daily doses for inhalation:

$$\begin{aligned}\text{LADD} &= (\text{I})(\text{EF})(\text{ED})/[(\text{BW})(\text{AT}_{\text{CAR}})] \\ \text{ADD} &= (\text{I})(\text{EF})(\text{ED})/[(\text{BW})(\text{AT}_{\text{NC}})]\end{aligned}$$

where:

LADD = lifetime average daily dose (mg/kg-day) (for carcinogens)
 ADD = average daily dose (mg/kg-day) (for non-carcinogens)
 I = daily inhalation potential dose rate (mg/day)
 EF = exposure frequency (days/year)
 ED = exposure duration (years)
 BW = body weight (kg)
 AT_{CAR} = averaging time for carcinogenic effects (days)
 AT_{NC} = averaging time for non-carcinogenic effects (days)

To estimate average daily doses from dermal contact:

$$\begin{aligned}\text{LADD} &= (\text{D})(\text{EF})(\text{ED})/[(\text{BW})(\text{AT}_{\text{CAR}})] \\ \text{ADD} &= (\text{D})(\text{EF})(\text{ED})/[(\text{BW})(\text{AT}_{\text{NC}})]\end{aligned}$$

where:

D = dermal potential dose rate (mg/day)

Parameter values for estimating worker's potential dose rates are presented in Table 3.19. Results of estimating inhalation and dermal ADDs (and the inhalation LADD for formaldehyde) are presented in Table 3.20 and Appendix E. Proprietary chemical results are not presented in order to protect proprietary chemical identities. The frequency data for activities pertaining to operating an MHC line could apply to more than one line worker, although they are assumed here to apply to a single, typical line operator. For example, facilities reported from one to 18 line operators working at one time, with an average of three line operators working the first shift. Therefore, the frequency of various worker activities pertaining to a single line operator may be overestimated by about a factor of three.

⁴ Different averaging times are used for characterizing risk for carcinogenic and non-carcinogenic effects. For carcinogenic agents, because even a single incidence of exposure is assumed to have the potential to cause cancer throughout an individual's lifetime, the length of exposure to that agent is averaged over a lifetime. An additional factor is that the cancer latency period may extend beyond the period of working years before it is discernible. For chemicals exhibiting non-cancer health effects from chronic (longer-term) exposure, where there is an exposure threshold (a level below which effects are not expected to occur); only the time period when exposure is occurring is assumed to be relevant and is used as the averaging time.

3.2 EXPOSURE ASSESSMENT

**Table 3.19 Parameter Values for Estimating Average Workplace Exposures
(for line operators)**

Parameter	Units	Value		Source of Data, Comments
Exposure Frequency (EF): Inhalation Exposure				
Line Operation & Working in Process Area	days/year	306		90th percentile, days/year MHC line operates from IPC Workplace Practices Questionnaire, all process types (average is 250 days/year).
EF: Dermal Exposure				
Line Operation	days/year	306		90th percentile, days/year MHC line operates from IPC Workplace Practices Questionnaire, all process types.
Chemical Bath Replacement	occur/year	electroless copper carbon conductive polymer graphite organic-palladium tin-palladium	1 - 50 1 - 145 1 - 20.5 7.3 - 145 1 - 230 1 - 230	90th percentiles for conveyORIZED processes from IPC Workplace Practices Questionnaire (see Table 3.14).
Conveyor Equipment Cleaning	occur/year	92		90th percentile from IPC Workplace Practices Questionnaire, for conveyORIZED lines.
Filter Replacement	occur/year	electroless copper carbon conductive polymer graphite non-formaldehyde electroless copper organic-palladium tin-palladium	100 20 74 103 17 50 74	90th percentiles from IPC Workplace Practices Questionnaire.
Chemical Bath Sampling	occur/year	electroless copper carbon conductive polymer graphite non-formaldehyde electroless copper organic-palladium tin-palladium	720 220 414 260 260 250 520	90th percentiles from IPC Workplace Practices Questionnaire, excluding automated sampling.
Parameters Pertaining to All Workplace Exposures (for Line Operators)				
Exposure Duration (ED)	years	25		95th percentile for job tenure (Bureau of Labor Statistics, 1990). (Median tenure for U.S. males is 4 years; Bureau of Labor Statistics, 1997.)
Body Weight (BW)	kg	70		Average for adults (EPA, 1991b).
Averaging Time (AT)	days			
AT _{CAR}		25,550		70 yrs (average lifetime)*365 d/yr
AT _{NC}		9,125		25 yrs (ED)*365 d/yr

**Table 3.20 Estimated Average Daily Dose (ADD) for Workplace Exposure -
Inhalation and Dermal**

Chemical ^a	ADD (mg/kg-day)		
	Inhalation	Dermal	
	Line Operator	Line Operator	Laboratory Technician
Electroless Copper, non-conveyorized			
Ammonium Chloride	NA	8.4e-02	2.1e-03
Benzotriazole	6.64e-04	2.5e-03	6.1e-05
Boric Acid	9.15e-04	3.3e-02	8.0e-04
Copper (I) Chloride	4.05e-04	4.4e-02	1.1e-03
Copper Sulfate; or Cupric Sulfate	4.45e-04	4.9e-02	1.2e-03
Dimethylaminoborane	1.04e-02	3.9e-03	9.6e-05
Dimethylformamide	7.58e-03	1.1e-03	2.8e-05
Ethanolamine	5.31e-02	1.0e-02	2.5e-04
2-Ethoxyethanol	7.79e+00	1.4e-01	3.4e-03
Ethylene Glycol	1.78e-02	2.5e-03	6.0e-05
Ethylenediaminetetraacetic Acid (EDTA)	2.74e-03	1.7e-05	4.2e-07
Fluoroboric Acid	1.18e-02	3.9e-01	9.6e-03
Formaldehyde	7.36e-02	1.1e-02	2.6e-04
Formaldehyde (LADD) ^b	2.63e-02	NA	NA
Formic Acid	1.88e-01	3.5e-02	8.5e-04
Hydrochloric Acid	2.91e-05	9.0e-01	2.2e-02
Hydrogen Peroxide	8.87e-04	1.3e-01	3.2e-03
Hydroxyacetic Acid	1.68e-04	2.4e-02	5.9e-04
Isopropyl Alcohol; or 2-Propanol	2.81e+00	3.1e-02	7.7e-04
Magnesium Carbonate	5.35e-05	7.8e-03	1.9e-04
Methanol	1.24e+00	1.1e-02	2.8e-04
m-Nitrobenzene Sulfonic Acid	4.90e-06	8.8e-07	2.2e-08
p-Toluene Sulfonic Acid	NA	4.0e-03	9.8e-05
Palladium	NA	2.4e-03	5.8e-05
Peroxymonosulfuric Acid	1.15e-03	1.7e-01	4.2e-03
Potassium Bisulfate	6.15e-04	9.0e-02	2.2e-03
Potassium Cyanide	1.35e-05	1.5e-03	3.6e-05
Potassium Hydroxide	1.25e-05	5.4e-03	1.3e-04
Potassium Persulfate	4.37e-04	6.4e-02	1.6e-03
Potassium Sulfate	8.56e-04	1.3e-01	3.1e-03
Potassium-Sodium Tartrate	1.90e-03	2.1e-01	5.0e-03
Sodium Bisulfate	NA	4.6e-01	1.1e-02
Sodium Carbonate	3.03e-06	3.3e-04	8.03e-06
Sodium Chlorite	NA	3.0e-02	7.2e-04

3.2 EXPOSURE ASSESSMENT

Chemical ^a	ADD (mg/kg-day)		
	Inhalation	Dermal	
	Line Operator	Line Operator	Laboratory Technician
Sodium Cyanide	1.40e-05	1.5e-03	3.7e-05
Sodium Hydroxide	6.30e-04	8.5e-02	2.1e-03
Sodium Hypophosphite	NA	5.6e-02	1.4e-03
Sodium Sulfate	NA	8.3e-02	2.0e-03
Stannous Chloride	NA	6.7e-02	1.6e-03
Sulfuric Acid	6.67e-03	1.2e+00	2.9e-02
Tartaric Acid	6.24e-05	5.7e-05	1.4e-06
Triethanolamine; or 2,2',2''-Nitrilotris Ethanol	NA	3.5e-03	8.5e-05
Electroless Copper, conveyorized			
Ammonium Chloride	NA	2.1e-02	2.1e-03
Benzotriazole	NA	6.3e-04	6.1e-05
Boric Acid	NA	9.2e-03	8.0e-04
Copper (I) Chloride	NA	9.8e-03	1.1e-03
Copper Sulfate; or Cupric Sulfate	NA	1.1e-02	1.2e-03
Dimethylaminoborane	NA	1.1e-03	9.6e-05
Dimethylformamide	NA	2.8e-04	2.8e-05
Ethanolamine	NA	2.5e-03	2.5e-04
2-Ethoxyethanol	NA	3.5e-02	3.4e-03
Ethylene Glycol	NA	6.5e-04	6.0e-05
Ethylenediaminetetraacetic Acid (EDTA)	NA	3.8e-06	4.2e-07
Fluoroboric Acid	NA	9.4e-02	9.6e-03
Formaldehyde	NA	2.4e-03	2.6e-04
Formic Acid	NA	8.6e-03	8.5e-04
Hydrochloric Acid	NA	2.1e-01	2.2e-02
Hydrogen Peroxide	NA	3.6e-02	3.2e-03
Hydroxyacetic Acid	NA	6.0e-03	5.9e-04
Isopropyl Alcohol; or 2-Propanol	NA	7.8e-03	7.7e-04
Magnesium Carbonate	NA	2.2e-03	1.9e-04
Methanol	NA	2.6e-03	2.8e-04
m-Nitrobenzene Sulfonic Acid	NA	2.2e-07	2.2e-08
p-Toluene Sulfonic Acid	NA	9.9e-04	9.8e-05
Palladium	NA	5.2e-04	5.8e-05
Peroxymonosulfuric Acid	NA	4.7e-02	4.2e-03
Potassium Bisulfate	NA	2.5e-02	2.2e-03
Potassium Cyanide	NA	3.3e-04	3.6e-05
Potassium Hydroxide	NA	1.4e-03	1.3e-04

Chemical ^a	ADD (mg/kg-day)		
	Inhalation	Dermal	
	Line Operator	Line Operator	Laboratory Technician
Potassium Persulfate	NA	1.8e-02	1.6e-03
Potassium Sulfate	NA	3.5e-02	3.1e-03
Potassium-Sodium Tartrate	NA	4.6e-02	5.0e-03
Sodium Bisulfate	NA	1.0e-01	1.1e-02
Sodium Carbonate	NA	7.3e-05	8.0e-06
Sodium Chlorite	NA	7.0e-03	7.2e-04
Sodium Cyanide	NA	3.4e-04	3.7e-05
Sodium Hydroxide	NA	1.9e-02	2.1e-03
Sodium Hypophosphite	NA	1.3e-02	1.4e-03
Sodium Sulfate	NA	1.8e-02	2.0e-03
Stannous Chloride	NA	1.5e-02	1.6e-03
Sulfuric Acid	NA	3.2e-01	2.9e-02
Tartaric Acid	NA	1.3e-05	1.4e-06
Triethanolamine; or 2,2',2''-Nitrilotris Ethanol	NA	8.6e-04	8.5e-05
Carbon, conveyORIZED			
Copper Sulfate; or Cupric Sulfate	NA	1.7e-02	1.4e-04
Ethanolamine	NA	9.6e-03	1.3e-04
Potassium Hydroxide	NA	7.3e-02	1.2e-03
Sodium Persulfate	NA	7.0e-01	5.7e-03
Sulfuric Acid	NA	6.4e-03	5.3e-05
Conductive Polymer, conveyORIZED			
1H-Pyrrole	NA	2.6e-02	3.3e-04
Peroxymonosulfuric Acid; or Potassium Peroxymonosulfate	NA	7.0e-01	8.8e-03
Phosphoric Acid	NA	1.0e-01	1.3e-03
Sodium Carbonate	NA	2.5e-02	3.3e-04
Sodium Hydroxide	NA	2.7e-03	4.0e-05
Sulfuric Acid	NA	1.4e-02	1.8e-03
Graphite, conveyORIZED			
Ammonia	NA	4.2e-03	3.3e-04
Copper Sulfate; or Cupric Sulfate	NA	1.1e-02	4.5e-04
Ethanolamine	NA	5.3e-03	3.2e-04
Graphite	NA	9.8e-02	7.7e-03
Peroxymonosulfuric Acid; or Potassium Peroxymonosulfate	NA	1.2e-01	5.1e-03
Potassium Carbonate	NA	2.1e-02	1.3e-03
Sodium Persulfate	NA	2.4e-01	9.7e-03
Sulfuric Acid	NA	2.4e-01	1.0e-02

3.2 EXPOSURE ASSESSMENT

Chemical ^a	ADD (mg/kg-day)		
	Inhalation	Dermal	
	Line Operator	Line Operator	Laboratory Technician
Non-Formaldehyde Electroless Copper, non-conveyorized			
Copper Sulfate; or Cupric Sulfate	1.47e-03	1.7e-01	2.7e-04
Hydrochloric Acid	NA	2.2e-02	3.4e-05
Hydrogen Peroxide	5.01e-04	1.2e-01	1.9e-04
Isopropyl Alcohol; or 2-Propanol	3.93e-01	1.3e-02	2.1e-05
Potassium Hydroxide	7.99e-06	2.2e-03	3.5e-06
Potassium Persulfate	3.04e-04	7.2e-02	1.1e-04
Sodium Chlorite	NA	3.3e-02	5.2e-05
Sodium Hydroxide	9.31e-06	2.2e-03	3.5e-06
Stannous Chloride	NA	6.9e-02	1.1e-04
Sulfuric Acid	7.94e-04	1.7e-01	2.6e-04
Organic-Palladium, non-conveyorized			
Hydrochloric Acid	NA	6.4e-02	2.2e-04
Sodium Bisulfate	NA	7.8e-01	2.7e-03
Sodium Carbonate	NA	2.3e-01	7.8e-04
Sodium Hypophosphite	NA	3.2e-02	1.1e-04
Sodium Persulfate	NA	7.8e-01	2.7e-03
Trisodium Citrate 5.5-Hydrate; or Sodium Citrate	NA	6.7e-03	2.3e-05
Organic-Palladium, conveyorized			
Hydrochloric Acid	NA	1.8e-02	2.2e-04
Sodium Bisulfate	NA	1.5e-01	2.6e-03
Sodium Carbonate	NA	4.8e-02	7.8e-04
Sodium Hypophosphite	NA	6.1e-03	1.1e-04
Sodium Persulfate	NA	1.5e-01	2.6e-03
Trisodium Citrate 5.5-Hydrate; or Sodium Citrate	NA	1.4e-03	2.3e-05
Tin-Palladium, non-conveyorized			
1,3-Benzenediol	NA	9.7e-03	9.7e-05
Copper (I) Chloride	NA	2.3e-02	2.3e-04
Copper Sulfate; or Cupric Sulfate	3.95e-04	1.3e-01	1.2e-03
Ethanolamine	1.07e-01	2.7e-02	2.7e-04
Fluoroboric Acid	9.45e-03	1.7e-01	1.7e-03
Hydrochloric Acid	NA	2.9e-01	2.9e-03
Hydrogen Peroxide	5.20e-04	1.6e-01	1.5e-03
Isopropyl Alcohol; or 2-Propanol	1.58e+00	1.6e-02	1.6e-04
Lithium Hydroxide	NA	1.8e-01	1.8e-03
Palladium	NA	8.5e-03	8.5e-05

Chemical ^a	ADD (mg/kg-day)		
	Inhalation	Dermal	
	Line Operator	Line Operator	Laboratory Technician
Palladium Chloride	NA	5.3e-03	5.3e-05
Potassium Carbonate	NA	2.9e+00	2.9e-02
Sodium Bisulfate	NA	7.9e-01	7.9e-03
Sodium Chloride	NA	9.0e+00	9.0e-02
Sodium Hydroxide	NA	2.6e-01	2.6e-03
Sodium Persulfate	4.49e-03	1.3e+00	1.3e-02
Stannous Chloride	NA	2.8e-01	2.8e-03
Sulfuric Acid	6.21e-04	1.9e+00	1.9e-02
Triethanolamine; or 2,2',2''-Nitrilotris Ethanol	NA	2.4e-03	2.4e-05
Vanillin	4.33e-04	3.0e-03	3.0e-05
Tin-Palladium, conveyorized			
1,3-Benzenediol	NA	2.7e-03	9.7e-05
Copper (I) Chloride	NA	8.1e-03	2.3e-04
Copper Sulfate; or Cupric Sulfate	NA	4.9e-02	1.2e-03
Ethanolamine	NA	1.2e-02	2.7e-04
Fluoroboric Acid	NA	6.0e-02	1.7e-03
Hydrochloric Acid	NA	1.1e-01	2.9e-03
Hydrogen Peroxide	NA	6.1e-02	1.6e-03
Isopropyl Alcohol; or 2-Propanol	NA	8.4e-03	1.6e-04
Lithium Hydroxide	NA	6.5e-02	1.8e-03
Palladium	NA	2.4e-03	8.5e-05
Palladium Chloride	NA	1.5e-03	5.3e-05
Potassium Carbonate	NA	1.0e+00	2.9e-02
Sodium Bisulfate	NA	3.3e-01	7.9e-03
Sodium Chloride	NA	3.3e+00	9.0e-02
Sodium Hydroxide	NA	9.2e-02	2.6e-03
Sodium Persulfate	NA	5.2e-01	1.3e-02
Stannous Chloride	NA	7.9e-02	2.8e-03
Sulfuric Acid	NA	1.2e+00	1.9e-02
Triethanolamine; or 2,2',2''-Nitrilotris Ethanol	NA	1.2e-03	2.4e-05
Vanillin	NA	8.4e-04	3.0e-05

^a Proprietary chemical results are not presented in order to protect proprietary chemical identities.

^b LADD is calculated using a carcinogen averaging time (AT_{CAR}) of 70 years.

Note: The numeric format used in these tables is a form of scientific notation, where the “e” replaces the “x 10^{xx}” in scientific notation. Scientific notation is typically used to present very large or very small numbers. For example, 1.2e-04 is the same as 1.2 x 10⁻⁴, which is the same as 0.00012 in common decimal notation.

NA: Not Applicable. A number was not calculated because the chemical’s vapor pressure is below the 1 x 10⁻³ torr cutoff and is not used in any sparged bath. Inhalation exposures are therefore expected to be negligible. LADDs were not calculated for dermal exposure.

Population Exposure

The equation for estimating ADDs from inhalation for a person residing near a facility is:

$$LADD = (Ca)(IR)(EF)(ED)/[(BW)(AT_{CAR})]$$

$$ADD = (Ca)(IR)(EF)(ED)/[(BW)(AT_{NC})]$$

where:

LADD = lifetime average daily dose (mg/kg-day) (for carcinogens)

ADD = average daily dose (mg/kg-day) (for non-carcinogens)

Ca = chemical concentration in air (mg/m³) (from air dispersion modeling, described in Section 3.2.3)

IR = inhalation rate (m³/day)

EF = exposure frequency (day/yr)

ED = exposure duration (years)

BW = average body weight (kg)

AT_{CAR} = averaging time for carcinogenic effects (days)

AT_{NC} = averaging time for non-carcinogenic chronic effects (days)

Table 3.21 presents values used for these parameters.

Table 3.21 Parameter Values for Estimating Nearby Residential Inhalation Exposure

Parameter	Units	Value	Source of Data, Comments
Ca	mg/m ³		Modeled, varies by chemical and process type.
IR	m ³ /day	15	Total home exposures for adults based on activity patterns and inhalation rates (EPA, 1997).
EF	days/year	350	Assumes 2 weeks per year spent away from home (EPA, 1991b).
ED	years	30	National upper 90th percentile at one residence (EPA, 1990).
BW	kg	70	Average value for adults (EPA, 1991b).
AT	days		
AT _{CAR}		25,550	70 yrs*365 days/year
AT _{NC}		10,950	ED * 365 days/year

Results for general population inhalation exposure are presented in Table 3.22 and Appendix E. Proprietary chemical results are not presented in order to protect proprietary chemical identities.

Table 3.22 Estimated Average Daily Dose (ADD) for General Population Inhalation Exposure

Chemical^a	ADD (mg/kg-day)
Electroless Copper, non-conveyORIZED	
2-Ethoxyethanol	6.5e-04
Formaldehyde	7.4e-06
Formaldehyde (LADD) ^b	2.6e-06
Isopropyl Alcohol; or 2-Propanol	2.4e-04
Methanol	1.0e-04
Electroless Copper, conveyORIZED	
2-Ethoxyethanol	7.0e-04
Formaldehyde	2.0e-05
Formaldehyde (LADD) ^b	7.0e-06
Formic Acid	3.5e-05
Isopropyl Alcohol; or 2-Propanol	4.6e-04
Methanol	1.9e-04
Non-Formaldehyde Electroless Copper, non-conveyORIZED	
Isopropyl Alcohol; or 2-Propanol	3.3e-05
Tin-Palladium, non-conveyORIZED	
Isopropyl Alcohol; or 2-Propanol	1.3e-04
Tin-Palladium, conveyORIZED	
Ethanolamine	2.3e-05
Isopropyl Alcohol; or 2-Propanol	1.0e-04

^a Only those chemicals with an emission rate at least 23 kg/year (44 mg/min), plus formaldehyde, are listed. Carbon, conductive polymer, graphite, and organic-palladium had no modeled emission rates above this cut-off. Also, proprietary chemical results are not presented in order to protect proprietary chemical identities.

^b LADD is calculated using a carcinogen averaging time (AT_{CAR}) of 70 years.

Note: The numeric format used in these tables is a form of scientific notation, where the “e” replaces the “x 10³” in scientific notation. Scientific notation is typically used to present very large or very small numbers. For example, 1.2e-04 is the same as 1.2 x 10⁻⁴, which is the same as 0.00012 in common decimal notation.

3.2.5 Uncertainty and Variability

Because of both the uncertainty inherent in the parameters and assumptions used in estimating exposure, and the variability that is possible within a population, there is no one number that can be used to describe exposure. In addition to data and modeling limitations, discussed in Sections 3.2.3, sources of uncertainty in assessing exposure include the following:

- Accuracy of the description of exposure setting: how well the model facility used in the assessment characterizes an actual facility; the likelihood of exposure pathways actually occurring (scenario uncertainty).

3.2 EXPOSURE ASSESSMENT

- Missing data and limitations of workplace practices data: this includes possible effects of any chemicals that may not have been included (e.g., minor ingredients in the formulations and proprietary chemical identities not disclosed by suppliers⁵); possible effects of side reactions in the baths, which were not considered; and questionnaire data with limited facility responses.
- Estimating exposure levels from averaged data and modeling in the absence of measured, site-specific data.
- Data limitations in the Source Release Assessment: releases to surface water and land could not be characterized quantitatively, as discussed in Section 3.1.
- Chemical fate and transport model applicability and assumptions: how well the models and assumptions represent the situation being assessed and the extent to which the models have been validated or verified (model uncertainty).
- Parameter value uncertainty, including measurement error, sampling error, parameter variability, and professional judgement.
- Uncertainty in combining pathways for an exposed individual.

A method typically used to provide information about the position an exposure estimate has in the distribution of possible outcomes is the use of exposure (or risk) descriptors. EPA's *Guidelines for Exposure Assessment* (EPA, 1992b) provides guidance on the use of risk descriptors, which include the following:

- *High-end*: approximately the 90th percentile of the actual (measured or estimated) distribution. This is a plausible estimate of individual risk for those persons at the upper end of the exposure distribution, and is not higher than the individual in the population who has the highest exposure.
- *Central tendency*: either an average estimate (based on average values for the exposure parameters) or a median estimate (based on 50th percentile or geometric mean values).
- *What-if*: represents an exposure estimate based on postulated questions (e.g., what if the air ventilation rates were ...), in this case, making assumptions based on limited data so that the distribution is unknown. If any part of the exposure assessment qualifies as a "what-if" descriptor, then the entire exposure assessment is considered "what-if."

This exposure assessment uses whenever possible a combination of central tendency (either an average or median estimate) and high-end (90th percentile)⁶ assumptions, as would be used for an overall high-end exposure estimate. The 90th percentile is used for:

⁵ Electrochemicals, LeaRonal, and Solution Technology Systems provided information on proprietary chemical ingredients to the project. Atotech provided information on one proprietary ingredient. W.R. Grace was making arrangements to transfer information on proprietary chemical ingredients in the conductive ink technology when it was determined that this information was no longer necessary because risk from the conductive ink technology could not be characterized. The other suppliers participating in the project (Enthone-OMI, MacDermid, and Shipley) declined to provide proprietary information on their MHC technologies. The absence of information on proprietary chemical ingredients is a significant source of uncertainty in the risk characterization. Risk information for proprietary ingredients is presented in this CTSA, but chemical identities, concentrations, and chemical properties are not listed.

⁶ For exposure data from the IPC Workplace Practices Questionnaire, this means that 90 percent of the facilities reported a lower value, and ten percent reported a higher value.

- Hours per day of workplace exposure.
- Exposure frequency (days per year).
- Exposure duration in years (90th percentile for occupational and 95th percentile for residential exposures).
- The time and frequency of chemical bath and filter replacements, conveyor equipment cleaning and chemical bath sampling (minutes per occurrence and number of occurrences per year), and estimated workplace air concentrations.

Average values are used for:

- Body weight.
- Concentration of chemical in bath.
- The number of baths in a given process.

However, because some data, especially pertaining to bath concentrations and inhalation exposure are limited, and this exposure assessment does not apply to a specific facility, the entire exposure assessment should be considered “what-if.”

3.2.6 Summary

This exposure assessment uses a “model facility” approach, with the goal of comparing the exposures and health risks of one MHC technology to the exposures and risks associated with switching to another technology. As much as possible, reasonable and consistent assumptions are used across alternatives. Data to characterize the model facility and exposure patterns for each MHC technology were aggregated from a number of sources, including PWB shops in the U.S. and abroad, supplier data, and input from PWB manufacturers at project meetings. Thus, the model facility is not entirely representative of any one facility, and actual exposure (and risk) could vary substantially, depending on site-specific operating conditions and other factors.

Chemical exposures to PWB workers and the general population from day-to-day MHC line operations were estimated by combining information gathered from industry (IPC Workplace Practices Questionnaire, MSDSs, and other available information) with standard EPA exposure assumptions for inhalation rate, surface area of dermal contact and other parameters, as discussed in the exposure assessment. The pathways identified for potential exposure from MHC process baths were inhalation and dermal contact for workers, and inhalation contact only for the general populace living near a PWB facility.

Environmental releases to surface water were not quantified due to a lack of data and the limited scope of this assessment. Chemical constituents and concentrations in wastewater could not be adequately characterized (see Section 3.2.3). Nor were the possible impacts of short-term exposures to high levels of hazardous chemicals addressed, such as those that could occur from chemical fires, spills, or other periodic releases.

Inhalation exposure could occur by breathing air containing vapor or aerosol-phase chemicals from the MHC process line. Inhalation exposures to workers are estimated only for non-conveyorized lines; inhalation exposure to workers from conveyorized MHC lines was assumed to be negligible because the lines are typically enclosed and vented to the outside.

3.2 EXPOSURE ASSESSMENT

The daily intake for inhalation exposure to workers was calculated by first modeling chemical emissions from MHC baths with three air-transport mechanisms: liquid surface diffusion (desorption), bubble desorption, and aerosol generation and ejection. This chemical emission rate was combined with information from the IPC Workplace Practices Questionnaire regarding process room size and air turnover rate to estimate an average indoor air concentration for the process area. General room ventilation was assumed, although the majority of shops have local ventilation on chemical tanks. An uncertainty and sensitivity analysis of the air transport models suggests that the air turnover (ventilation) rate assumption greatly influences the estimated air concentration in the process area because of its large variability.

Inhalation exposure to the human population surrounding PWB plants was estimated using the Industrial Source Complex - Long Term (ISCLT) air dispersion model. The modeled air concentrations of each contaminant were determined at 100 meters radially from a PWB facility, and the highest estimated air concentration was used. This model estimates air concentration from the process bath emission rates. These emissions were assumed to be vented to the ambient environment at the rate emitted from the baths, for all process alternatives. Inhalation exposures estimated for the public living 100 meters away from a PWB facility were very low (approximately 10,000 times lower than occupational exposures).

Dermal exposure could occur when skin comes in contact with the bath solution while dipping boards, adding replacement chemicals, etc. Although the data suggest that most MHC line operators do wear gloves, it was assumed in this evaluation that workers do not wear gloves to account for the fraction that do not. Otherwise, dermal exposure is expected to be negligible. For dermal exposure, the concentration of chemical in the bath and duration of contact for workers was obtained from the IPC Workplace Practices Questionnaire information. A permeability coefficient (rate of penetration through skin) was estimated for organics and a default rate assumption was used for inorganics. Another source of uncertainty in dermal modeling lies with the assumed duration of contact. The worker is assumed to have potential dermal contact for the entire time spent in the MHC area, divided equally among the baths. (This does not mean that a worker has both hands immersed in a bath for that entire time; but that the skin is in contact with bath solution, i.e., the hands may remain wet from contact.) This assumption may result in an overestimate of dermal exposure.

Assumptions and parameter values used in these equations are presented throughout this section. Complete results of the exposure calculations are presented in Appendix E, except proprietary chemical results are not presented in order to protect proprietary chemical identities. Exposure estimates are based on a combination of high end (90th percentile)⁷ and average values, as would be used for a high-end exposure estimate. The 90th percentile was used for hours per day of workplace exposure, exposure frequency (days per year), exposure duration in years (90th percentile for occupational and 95th percentile for residential exposures), and the time and frequency of chemical bath and filter replacements, conveyor equipment cleaning and chemical bath sampling (minutes per occurrence and number of occurrences per year) and estimated workplace air concentrations. The average value was used for body weight, concentration of chemical in bath, and the number of baths in a given process. However, because some data,

⁷ For exposure data from the IPC Workplace Practices Questionnaire, this means that 90 percent of the facilities reported a lower value, and ten percent reported a higher value.

especially pertaining to bath concentrations and inhalation exposure are limited, and this exposure assessment does not apply to a specific facility, the entire exposure assessment should be considered “what-if.”